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STRESS ANALYSIS OF PATHFINDER-II MODELS

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S. C. MEHROTRA AND C. T. L. MILLS

VIGYAN RESEARCH ASSOCIATES, INC.
HAMPTON, VIRGINIA

CONTRACT NAS1-16114
OCTOBER 1984

[redacted]

NASA

National Aeronautics and
Space Administration

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Hampton, Virginia 23665

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INTRODUCTION

Pathfinder II is a fighter model to be tested in the National Transonic Facility (NTF) at NASA Langley Research Center. The geometry and dimensions of this model are shown in figure 1. The leading-edge sweep angle for this model is 45 degrees and the average maximum airfoil thickness ratio is about 4.5 percent. This model is highly cambered and twisted. Since the model is to be equipped with various removable leading- and trailing-edge flaps, several different configurations were studied for stress analysis. In the early stages of the stress analysis study, the airfoil sections as given in Table I were used for the structural modeling (provided by NTF Aerodynamics Branch). As the work progressed these airfoil sections were replaced by the actual metal coordinates (provided by Model Engineering Section).

MATHEMATICAL MODEL

The mathematical representation for this wing model assumes that the fuselage is a rigid body and that the wing root is rigidly fixed at $2y/b = 0.13$ from the fuselage center line (fig. 2). The SPAR computer program (ref. 1) has been used for the structural analysis of these models.

The SPAR computer program can mathematically model a wing by utilizing plate elements and/or solid elements. Thus, a wing may be divided into a number of small plate or solid structural elements. A plate element is a constant thickness plate; whereas a solid element is an element whose thickness may vary in the chordwise and/or spanwise directions.

The leading-edge sweep angle for this model is 45 degrees. When the sweep angle is this large, the solid elements (S61 and S81) of SPAR program do not yield accurate results and, hence, the constant thickness plate elements (E43) were used for the structural modeling. Previous experience has shown these elements to be quite accurate (ref. 2). A typical finite element mesh for the Pathfinder II wing model is shown in figure 3. Whenever the flaps were connected to the main wing by screws or pins, zero length beam elements (E25's) were used to model the screws and pins connecting flaps to the main wing.

Several of the models were reanalyzed by using NASTRAN to cross-check the numbers obtained using SPAR. In the NASTRAN models, QUAD2 elements were used for plate modeling and ELAS2 for zero length elements.

PRESSURE LOADING

The analysis of these models was performed for the maximum load condition. Corresponding to the maximum load condition, two different non-dimensional pressure coefficient, C_p, distributions have been used. Due to this, the study has been divided into Phases I and II. Under Phase I, different models of Pathfinder II were subjected to the C_p loading of figure 4. This loading yielded very high stress levels for all the models studied. Later, this loading was revised to make it more realistic to the actual loading. This C_p loading is shown in figure 5 and all the results corresponding to this loading are listed under Phase II study.

The non-dimensional pressure coefficients, C_p's, for the above two loading conditions, were converted into pressures by using:

$$p = p_\infty + C_p \, q_\infty$$

where p_∞ = 14.3921 psia and q_∞= 9.09 psia (i.e. 1309 lbs/ft^2). As the structural model is represented by plate elements the difference in the upper and lower surface pressures is calculated by using,

$$\Delta p = p_l - p_u = (C_{p_l} - C_{p_u}) \, q_\infty$$

The differential pressures are interpolated to obtain the pressures acting at different grid points of the model.

PHASE I STUDY

Flat Plate Model Without Flaps

All the grid points for this model were assumed to lie in the x-y plane. This model showed that the maximum principal stress of 37,000 psi occurs at $x/c = 0.60$ and $2y/b = 0.31$ (fig. 6).

Curved Plate Model Without Flaps

The actual coordinates of Pathfinder II show considerable amount of camber and so, henceforth, all the models were modeled by putting the grid points off the x-y plane. The grid points were assumed to lie along the camber line at each spanwise station. This model showed that the maximum principal stress of 41,000 psi occurs at $x/c = 0.95$ and $2y/b = 0.51$ (fig. 7).

Pressure Model Without Flaps

One of the designs under consideration for the Pathfinder II pressure model is to overcut the upper and lower surfaces of the wing by about 0.02 inches. After the pressure tubings are laid, the wing is to be nickel plated to the final desired shape. It was of interest to determine the maximum principal stress level for the overcut wing. This model shows that the maximum principal stress of 120,000 psi occurs at $x/c = 0.85$ and $2y/b = 1.0$ (fig. 8). This stress level is too high and is due to the fact that a large amount of material was taken out from the upper and lower surfaces of the trailing-edge near the wing tip, resulting in unrealistic modeling of this region.

Trailing-Edge Flap Model (Single Lap Joint Model)

In this model the trailing edge flap was assumed to be hinged at 76% chord line (fig. 9). The trailing edge flap was assumed to be connected to the main wing at 9 locations. At these 9 locations E25 elements were used and the corresponding points were constrained to move together in x, y and z directions. This model of Pathfinder II was analyzed to find the principal stress levels in the wing and the forces acting in the pins which connect the flap to the main wing. Nine pins were assumed in the model (fig. 10). This model showed that the maximum principal stress of 49,000 psi occurs at $x/c = 0.95$ and $2y/b = 0.51$ (fig. 11). The forces in the pins were of the order of 600 lbs, and resulted in unreasonably large shear stresses in the pins.

Trailing-Edge Flap Model With Flap Tracks (Single Lap Joint Model)

This model was slightly different than the previous model because at the four pin locations, where the pin shear stresses were large, the thickness of the wing was doubled to simulated the flap tracks. These gave slightly more depth of the screws and pins. Still the stress levels in the pins were large.

Leading- and Trailing-Edge Flap Model

This model also used single lap joints for the leading- and trailing-edge flaps. The planview of the model is shown in figure 12. In this model the leading edge flap was attached to the main wing by 9 pins/screws and the trailing edge by 9 pins/screws. This model also showed excessively large forces in the leading- and trailing-edge pins and screws.

Flap Model with Hinge Line at 50%

The planview of this model is shown in figure 13. Although, this model showed lower stress levels in the pins and screws, it was not acceptable to NTF Aerodynamics Branch personnel.

PHASE II STUDY

After studying the above mentioned models under the pressure loading of figure 4, this loading was revised to make loading realistic. This loading is shown in figure 5. Using this loading the previous models were not rerun because it was expected that it would not make much difference in the stress levels of the pins. Only the following two mathematical models were studied under this phase.

Single Lap Joint Model for Leading- and Trailing-Edge Flaps

In this model both leading- and trailing-edge flaps were modeled by single lap joints. Some of the properties of this model are given below:

Leading-edge screws	12
Leading-edge pins	11
Trailing-edge screws	12
Trailing-edge pins	11

All the pins were constrained in x and y directions to take out the shear forces only. The screws were constrained in z, θ_x and θ_y directions to take out tension/compression and bending. It was found that in this model the stress levels for both the pins and screws on the trailing-edge flap were unreasonably high. And so this model was taken out of consideration.

Alternating Surface Segmented Lap Joint Model

Under this scheme the leading-edge flap was modeled by using single lap joint (same as above model) and the trailing-edge flap by alternating surface segmented lap joint (fig. 14). The finite element mesh used for this model is shown in figure 15. This work was done by using three slightly different models. In all three of these models, there were 12 leading edge pins, 11 leading-edge screws and 16 trailing-edge screws. The number of trailing-edge side-edge (E25) elements were different. In this formulation, the leading-edge screws were constrained in z, θ_x and θ_y

directions, leading-edge pins in x and y directions, trailing-edge screws in x and z directions, and the lap joint side-edges under compression in y direction. In Model-I there were 14 side-edge E25 elements. When the deflections were checked; it was found that 7-E25 elements under tension were eliminated and so this had only 7-E25 elements. From Model-II 3-E25 elements which were on the lower surface were taken out and so the Model-III had only 4-E25 elements for edge modeling. This model gave us reasonable stress levels in the leading- and trailing-edge screws and reasonable bearing stresses on the edges. The location of pins and screws, which attach the leading- and trailing-edge flaps to the main wing, are shown in figure 16. The x - y location of these pins and screws are listed in Table III. Digitized stresses for this model under the loading of figure 5 are shown in figure 17. The forces and moments acting at all the screws and pins are listed in Table IV. These forces and moments were converted into stresses by the personnel in Model Engineering Section. It has been found that by using the proper pins and screws a reasonable factor of safety (3 to 4) could be achieved by using the alternating surface segmented lap joint of the trailing-edge flap and the ordinary lap joint for the leading-edge flap.

A small part of the study was focused towards freeing the leading- and trailing-edge flaps at the root i.e. fuselage. Here several different pin and screw combinations were studied. None of these resulted in improving the stress conditions in those pins and screws.

CONCLUSION

To produce shearing stresses in the pins and screws that are at acceptable levels, the alternating surface segmented lap joint method of attachment should be used on the trailing-edge flap and an ordinary lap joint for the leading-edge flap.

REFERENCES

1. Whetstone, W. D.; SPAR Structural Analysis System - Reference Manual, Vol. I, NASA CR-145098-1, February 1977.

2. Mehrotra, S. C., and Robinson, J. C.; Structural Modeling of High Reynolds Number Wind Tunnel Models, AIAA 12th Aerodynamic Testing Conference, Williamsburg, VA, 1982.

Table I

2y/b	Airfoil	$(t/c)_{max}$
0.13 to 0.20	RC1C	0.0650
0.20 to 0.40	RC2C	0.0447
0.50 to 1.00	RC3D	0.0448

TABLE II

MODELS STUDIED UNDER PHASE I STUDY

Model	Comments
Flat Plate Model Without Flaps	All these models showed large forces in pins and screws.
Curved Plate Model Without Flaps	
Pressure Model Without Flaps (Undercut for Nickel Plating)	
Trailing-Edge Flap Model (Single Lap Joint Model)	
Trailing-Edge Flap Model With Flap Tracks (Single Lap Joint Model)	
Leading- and Trailing-Edge Flap Model	
Flap Model With Hinge Line at 50 percent	

TABLE II

MODELS STUDIED UNDER PHASE II STUDY

Model	Comments
Single Lap Joint for Leading- and Trailing-Edge Flaps	Forces in pins & screws were large and so these forces were obtained in indirect manner by applying displacements on model. It resulted in the similar forces.
Alternating Surface Segmented Lap Foint for Trailing-Edge Flap and Single Lap Joint for Leading-Edge Flap	Model III was the worst case representation, but still has sufficient factor of safety for pins and screws.
Trailing-Edge Edges Model I 14 Model II 7 Model III 4 Models I, II and III used 12 leading-edge pins, 11 leading-edge screws and 16 trailing-edge screws.	

Table III

COORDINATES OF LEADING-EDGE SCREWS

#	X	Y
1	20.2615	2.3658
2	21.0288	3.2997
3	21.6477	4.0497
4	22.2588	4.7997
5	22.9441	5.6497
6	23.4588	6.2997
7	24.0549	7.0497
8	24.6131	7.7497
9	25.1678	8.4497
10	25.8391	9.2997
11	26.4668	10.0997
12	27.0154	10.7997

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COORDINATES OF LEADING-EDGE PINS

#	X	Y
1	20.5193	2.6828
2	21.4005	3.7497
3	22.0144	4.4997
4	22.5644	5.1747
5	23.1322	5.8872
6	23.6964	6.5997
7	24.2543	7.2997
8	24.8082	7.9943
9	25.5232	8.8997
10	26.0942	9.6247
11	26.6629	10.3497

COORDINATES OF TRAILING-EDGE SCREWS

#	X	Y
1	25.5185	2.0489
2	25.7959	2.6828
3	26.1595	3.4997
4	26.4037	4.0497
5	26.7285	4.7997
6	26.8909	5.1747
7	27.1882	5.8872
8	27.3585	6.2997
9	27.6722	7.0497
10	27.8732	7.5247
11	28.1690	8.2247
12	28.3583	8.6747
13	28.6213	9.2997
14	28.8573	9.8622
15	29.1508	10.5622
16	29.3287	10.9872

COORDINATES OF EDGES ALONG TRAILING-EDGE FLAP

#	X	Y
1	26.0705	3.2997
2	27.0901	5.6497
3	28.0720	7.9943
4	29.0617	10.3497

Table IV.

FORCES ON THE LEADING-EDGE SCREWS

INDEX	JOINT	P1	P2	P3	P4	P5	P6
1	591	0.00	0.00	161.58	172.29	35.02	0.00
	28	0.00	0.00	-161.58	-172.29	-35.02	0.00
2	594	0.00	0.00	259.98	144.88	50.01	0.00
	64	0.00	0.00	-259.98	-144.88	-50.01	0.00
3	597	0.00	0.00	164.15	113.91	41.04	0.00
	100	0.00	0.00	-164.15	-113.91	-41.04	0.00
4	600	0.00	0.00	156.25	75.20	30.21	0.00
	136	0.00	0.00	-156.25	-75.20	-30.21	0.00
5	604	0.00	0.00	80.85	47.63	16.41	0.00
	184	0.00	0.00	-80.85	-47.63	-16.41	0.00
6	607	0.00	0.00	34.55	38.76	8.96	0.00
	220	0.00	0.00	-34.55	-38.76	-8.96	0.00
7	610	0.00	0.00	45.45	24.17	6.05	0.00
	256	0.00	0.00	-45.45	-24.17	-6.05	0.00
8	613	0.00	0.00	22.66	12.20	2.25	0.00
	292	0.00	0.00	-22.66	-12.20	-2.25	0.00
9	616	0.00	0.00	18.37	8.55	-.75	0.00
	328	0.00	0.00	-18.37	-8.55	.75	0.00
10	620	0.00	0.00	-.25	3.56	-1.31	0.00
	376	0.00	0.00	.25	-3.56	1.31	0.00
11	623	0.00	0.00	-69.60	-2.29	.95	0.00
	412	0.00	0.00	69.60	2.29	-.95	0.00
12	626	0.00	0.00	-99.50	-9.74	.16	0.00
	448	0.00	0.00	99.50	9.74	-.16	0.00

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Table IV. Continued.

FORCES ON THE LEADING-EDGE PINS

INDEX	JOINT	P1	P2	P3	P4	P5	P6
1	592	247.60	-29.98	0.00	0.00	0.00	0.00
	40	-247.60	29.98	0.00	0.00	0.00	0.00
2	596	254.34	-47.31	0.00	0.00	0.00	0.00
	88	-254.34	47.31	0.00	0.00	0.00	0.00
3	599	173.25	-130.89	0.00	0.00	0.00	0.00
	124	-173.25	130.89	0.00	0.00	0.00	0.00
4	602	40.88	-124.67	0.00	0.00	0.00	0.00
	160	-40.88	124.67	0.00	0.00	0.00	0.00
5	605	-133.67	-155.81	0.00	0.00	0.00	0.00
	196	133.67	155.81	0.00	0.00	0.00	0.00
6	608	-225.49	-262.76	0.00	0.00	0.00	0.00
	232	225.49	262.76	0.00	0.00	0.00	0.00
7	611	-231.95	-246.38	0.00	0.00	0.00	0.00
	268	231.95	246.38	0.00	0.00	0.00	0.00
8	614	-252.03	-241.47	0.00	0.00	0.00	0.00
	304	252.03	241.47	0.00	0.00	0.00	0.00
9	618	-242.09	-324.62	0.00	0.00	0.00	0.00
	352	242.09	324.62	0.00	0.00	0.00	0.00
10	621	-286.84	-337.82	0.00	0.00	0.00	0.00
	388	286.84	337.82	0.00	0.00	0.00	0.00
11	624	-581.54	-51.04	0.00	0.00	0.00	0.00
	424	581.54	51.04	0.00	0.00	0.00	0.00

Table IV. Continued.

FORCES ON THE TRAILING-EDGE SCREWS

INDEX	JOINT	P1	P2	P3	P4	P5	P6
1	21	15.02	0.00	3.25	11.67	4.54	0.00
	630	-15.02	0.00	-3.25	-11.67	-4.54	0.00
2	45	-26.46	0.00	36.86	24.99	5.51	0.00
	632	26.46	0.00	-36.86	-24.99	-5.51	0.00
3	81	-1.69	0.00	11.08	27.52	6.52	0.00
	635	1.69	0.00	-11.08	-27.52	-6.52	0.00
4	105	-5.53	0.00	-26.02	22.36	9.29	0.00
	637	5.53	0.00	26.02	-22.36	-9.29	0.00
5	141	-28.34	0.00	5.95	20.76	10.57	0.00
	640	28.34	0.00	-5.95	-20.76	-10.57	0.00
6	165	-51.41	0.00	-39.56	19.81	13.54	0.00
	642	51.41	0.00	39.56	-19.81	-13.54	0.00
7	201	-70.51	0.00	-4.13	13.02	12.43	0.00
	645	70.51	0.00	4.13	-13.02	-12.43	0.00
8	225	-44.82	0.00	-8.27	10.29	7.30	0.00
	647	44.82	0.00	8.27	-10.29	-7.30	0.00
9	261	75.82	0.00	28.27	2.61	-.84	0.00
	650	-75.82	0.00	-28.27	-2.61	.84	0.00
10	285	145.68	0.00	16.89	-1.43	-1.91	0.00
	652	-145.68	0.00	-16.89	1.43	1.91	0.00
11	321	89.70	0.00	-7.69	3.61	-1.08	0.00
	655	-89.70	0.00	7.69	-3.61	1.08	0.00
12	345	18.58	0.00	-4.98	1.35	-.33	0.00
	657	-18.58	0.00	4.98	-1.35	.33	0.00
13	381	.71	0.00	-6.40	1.90	.77	0.00
	660	-.71	0.00	6.40	-1.90	-.77	0.00
14	405	12.33	0.00	-11.76	.51	1.65	0.00
	662	-12.33	0.00	11.76	-.51	-1.65	0.00
15	441	-31.20	0.00	-28.17	3.82	1.37	0.00
	665	31.20	0.00	28.17	-3.82	-1.37	0.00
16	465	-136.14	0.00	-21.03	1.63	.08	0.00
	667	136.14	0.00	21.03	-1.63	-.08	0.00

Table IV. Concluded.

FORCES ON EDGES ALONG TRAILING-EDGE FLAP

INDEX	JOINT	P1	P2	P3	P4	P5	P6
1	69	0.00	241.71	0.00	0.00	0.00	0.00
	634	0.00	-241.71	0.00	0.00	0.00	0.00
2	189	0.00	781.40	0.00	0.00	0.00	0.00
	644	0.00	-781.40	0.00	0.00	0.00	0.00
3	309	0.00	844.33	0.00	0.00	0.00	0.00
	654	0.00	-844.33	0.00	0.00	0.00	0.00
4	429	0.00	492.43	0.00	0.00	0.00	0.00
	664	0.00	-492.43	0.00	0.00	0.00	0.00

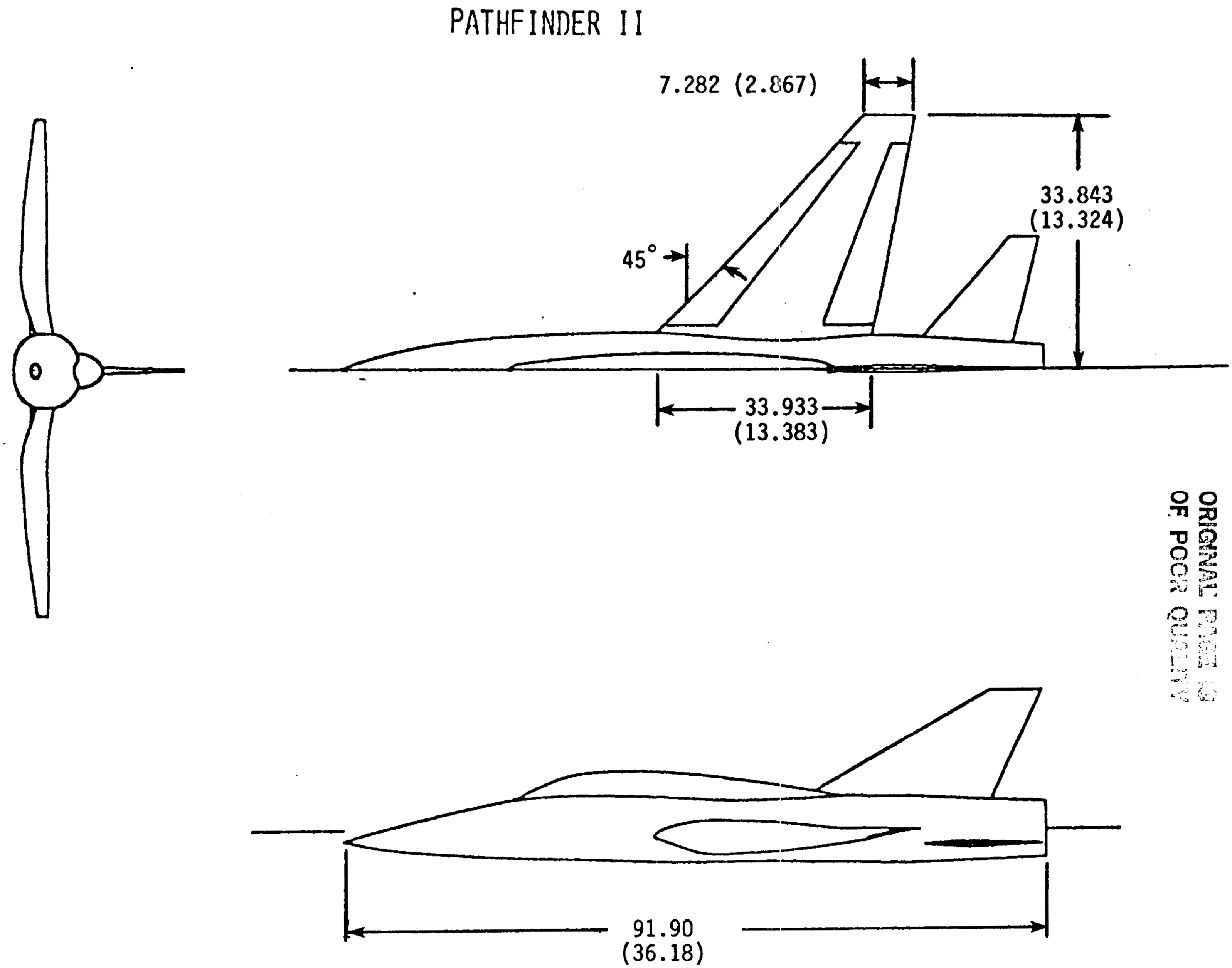

Figure 1. General Arrangement of PATHFINDER-II
Dimensions are in Centimeters(Inches)

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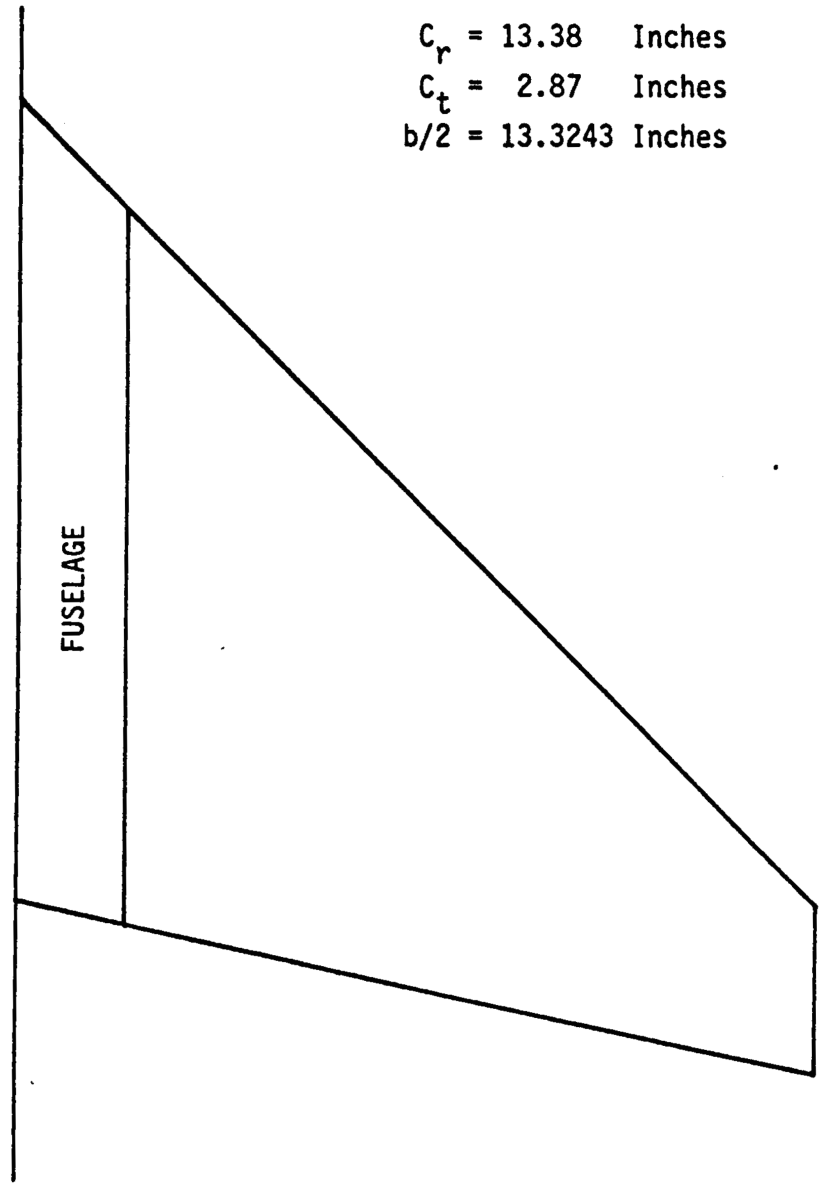

Figure 2. PATHFINDER-II Planview Without Flaps

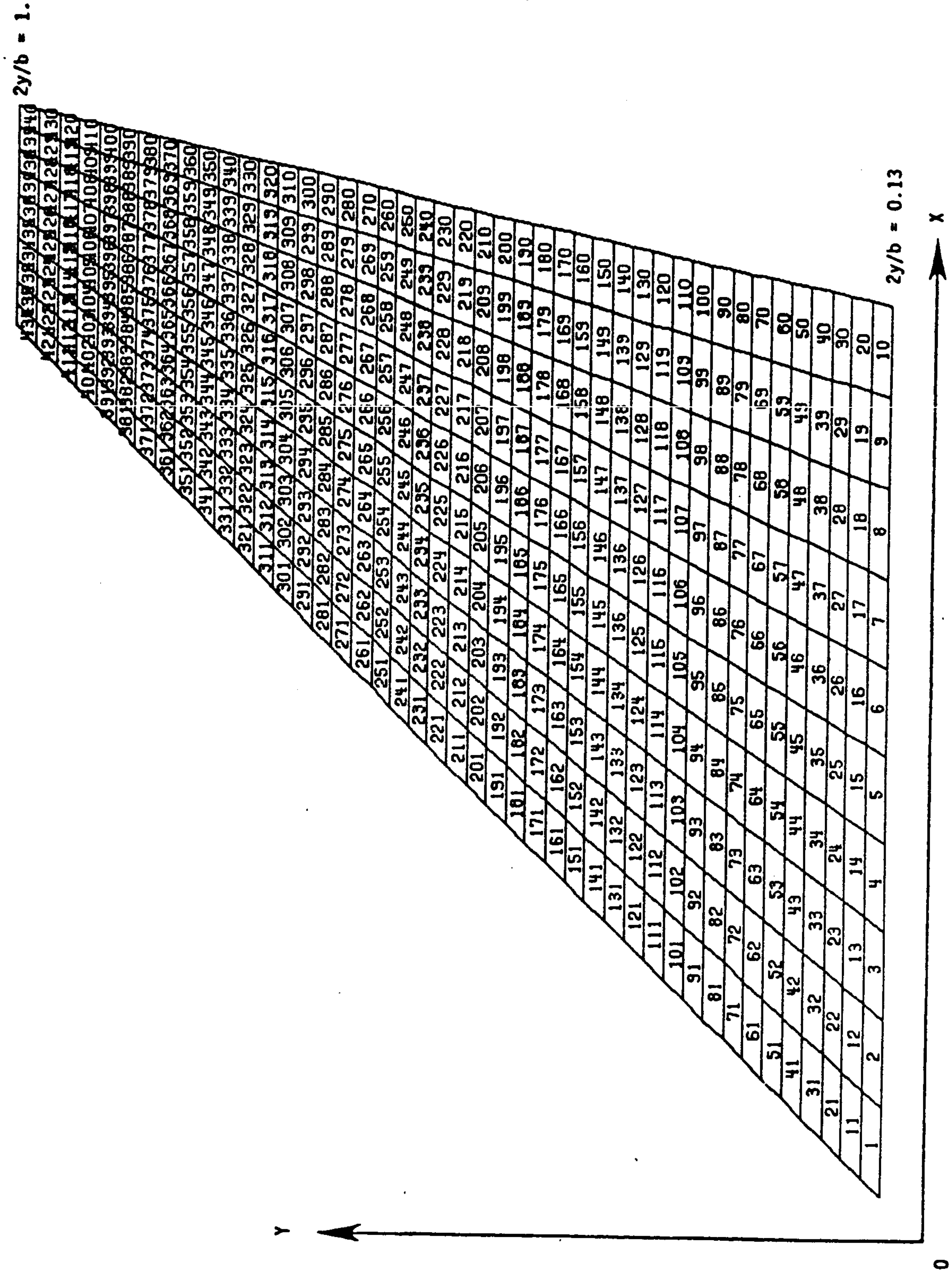

Figure 3. Plate Element Boundaries and Element Numbers for PATHFINDER-II

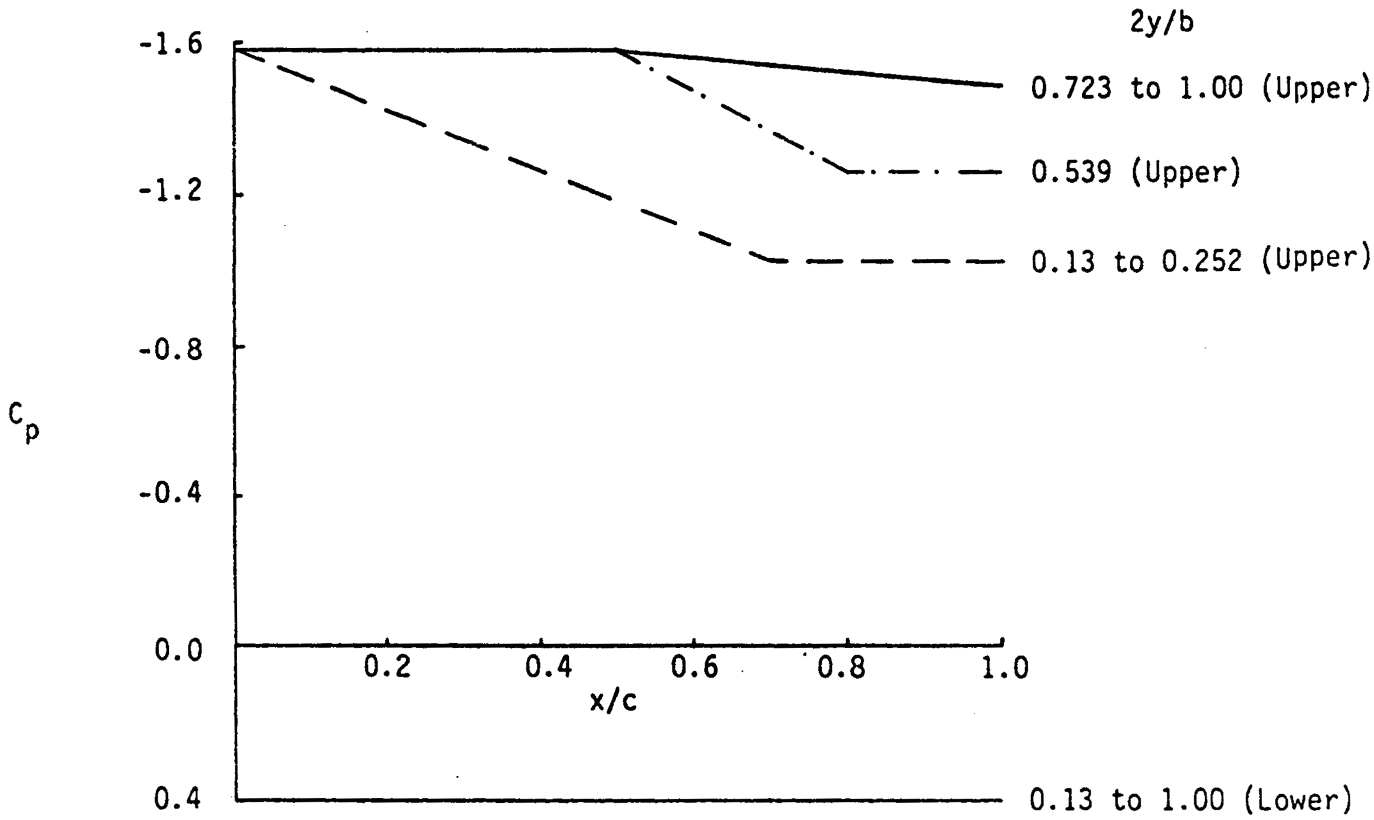

Figure 4. Pressure Coefficient Distribution used under PHASE-I

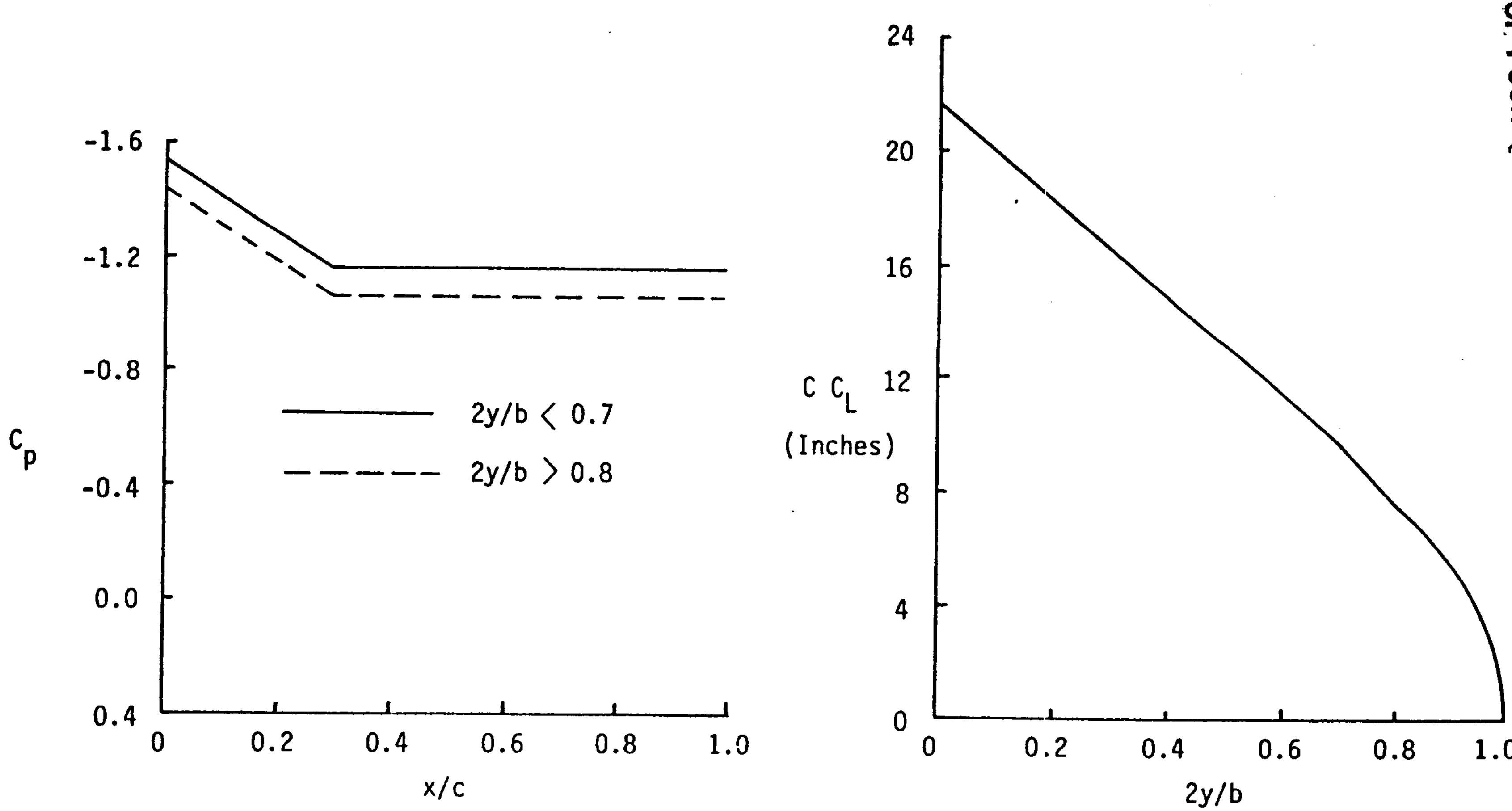

Figure 5. Pressure Coefficient and Spanwise Lift Distribution Used Under PHASE-II

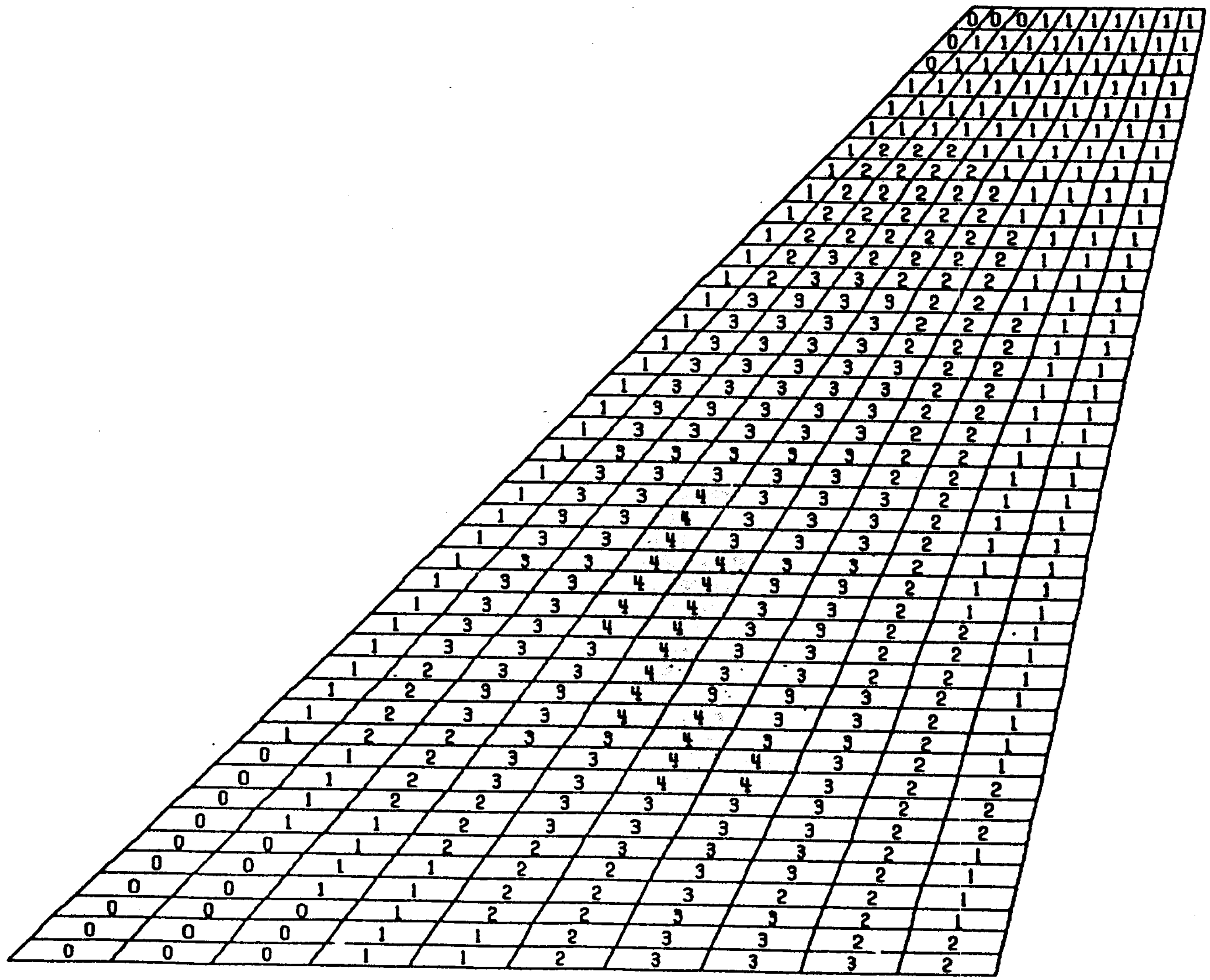

Figure 6. Digitized Principal Stresses at Element Centers for Flat Plate Model

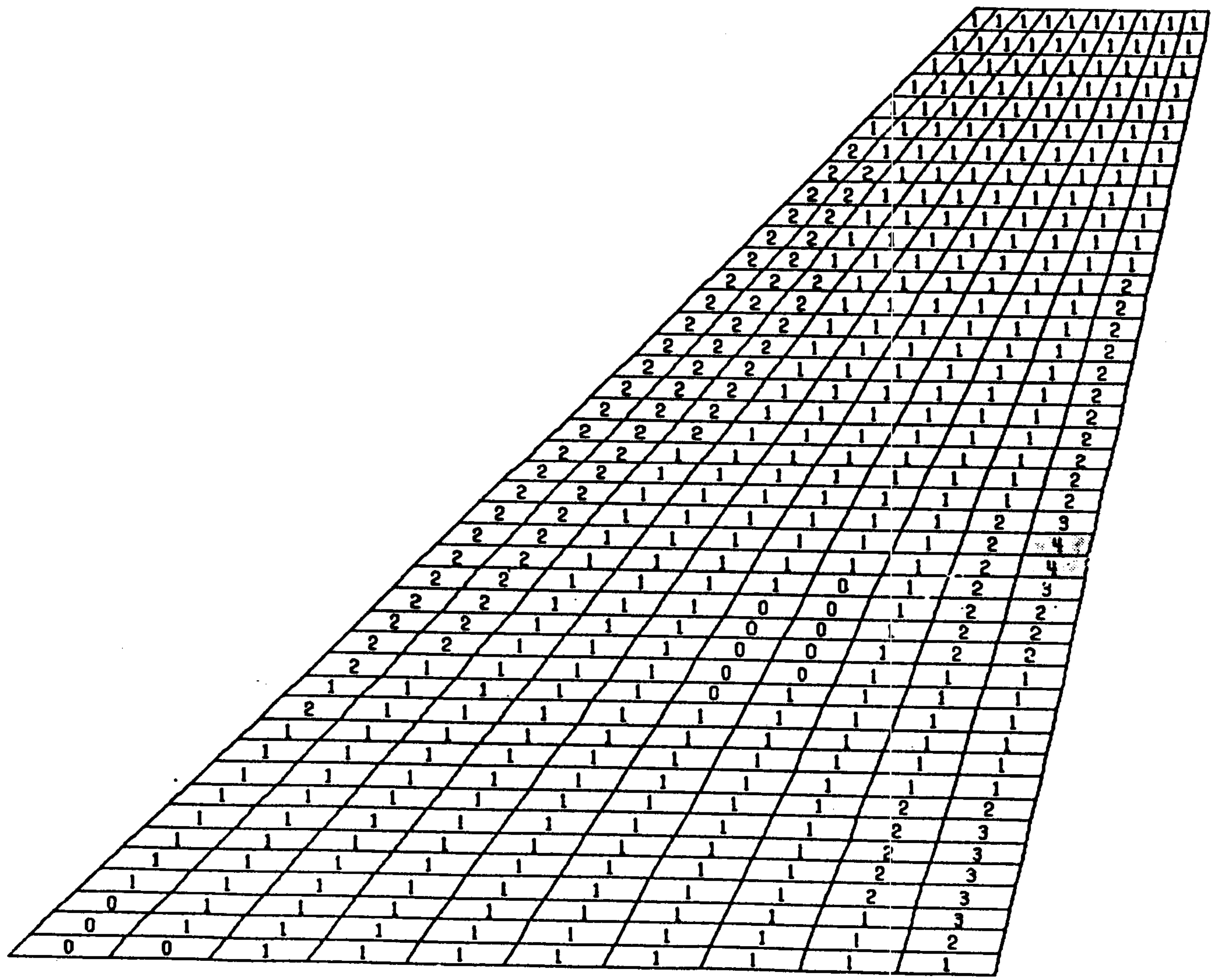

Figure 7. Digitized Principal Stresses at Element Centers for Curved Plate Model

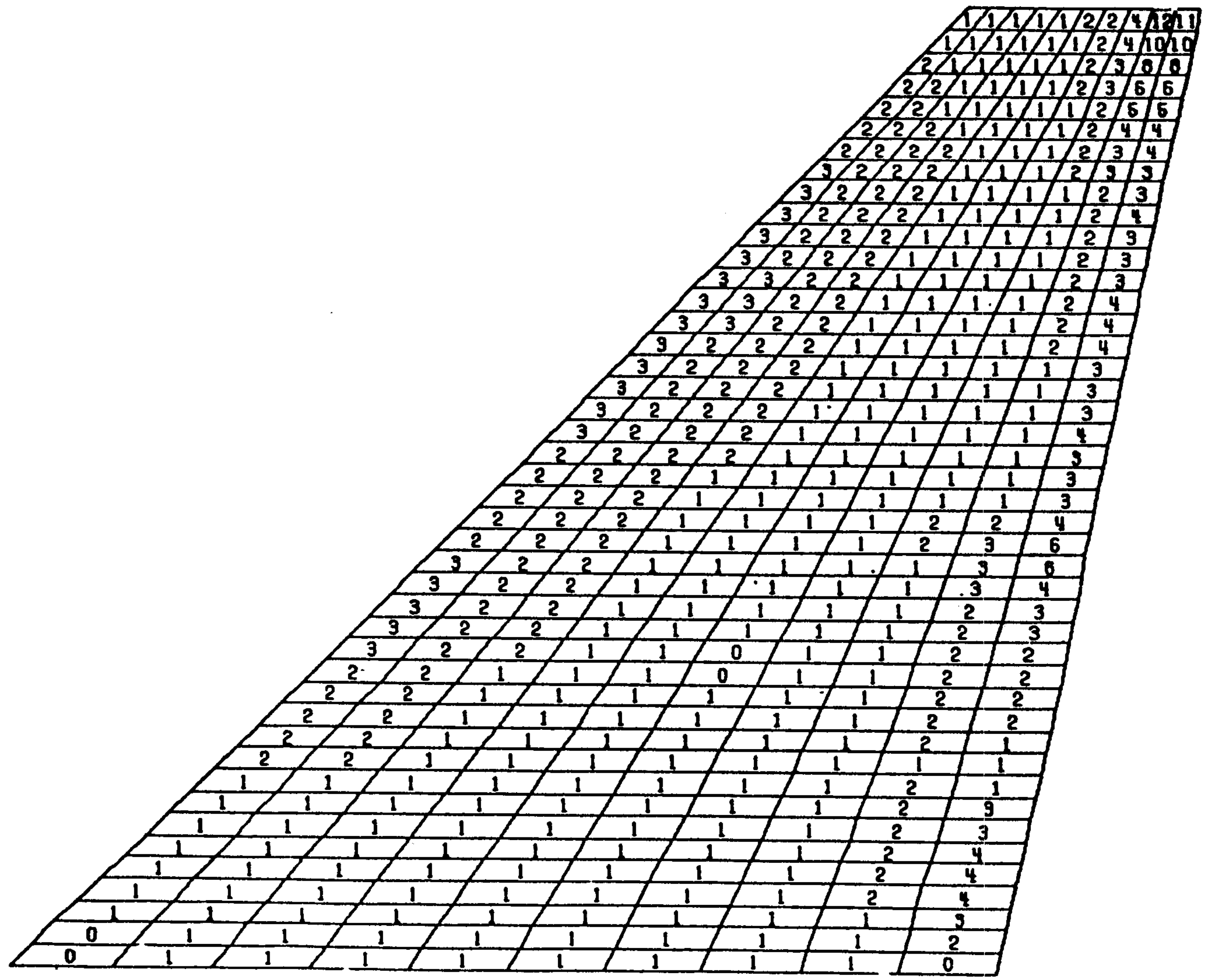

Figure 8. Digitized Principal Stresses at Element Centers for Pressure Model Without Flaps

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C_r = 13.38 Inches
C_t = 2.87 Inches
b/2 = 13.3243 Inches

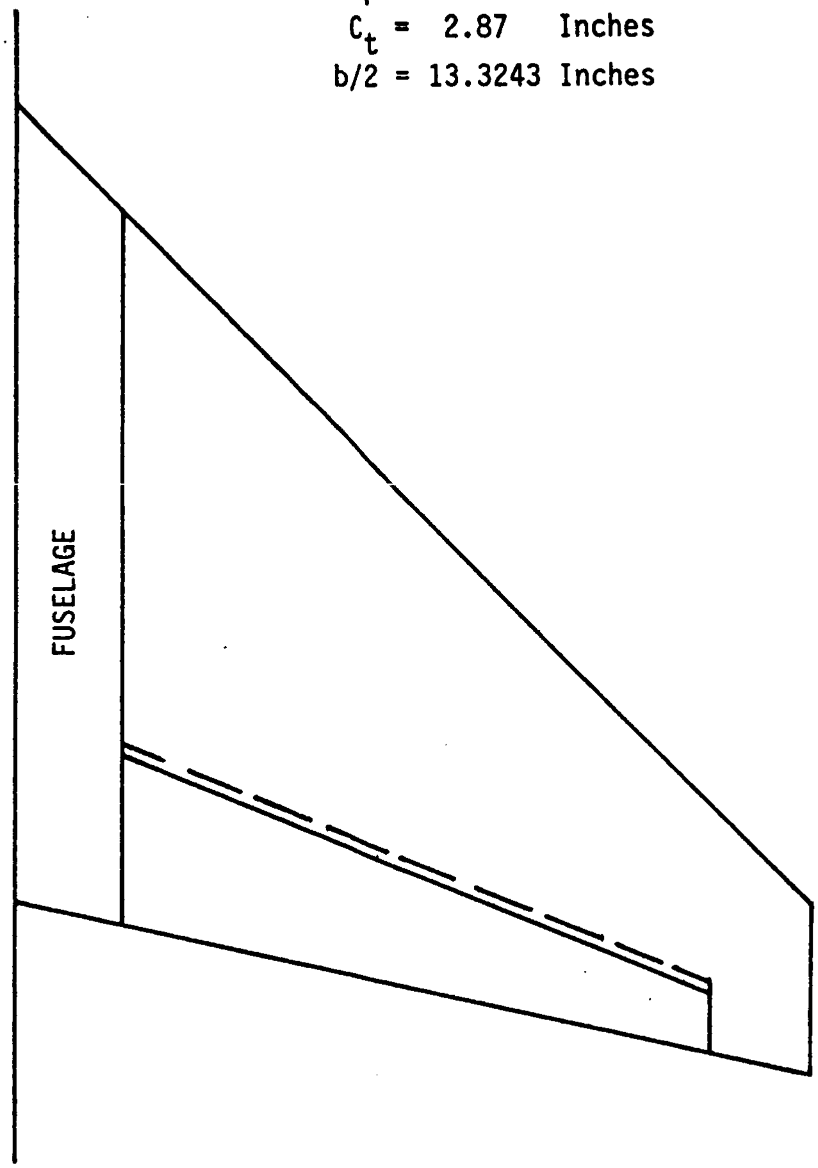

Figure 9. PATHFINDER-II Planview With Trailing-Edge Flap Line at 76 percent Chord-line (Trailing-Edge Flap Model)

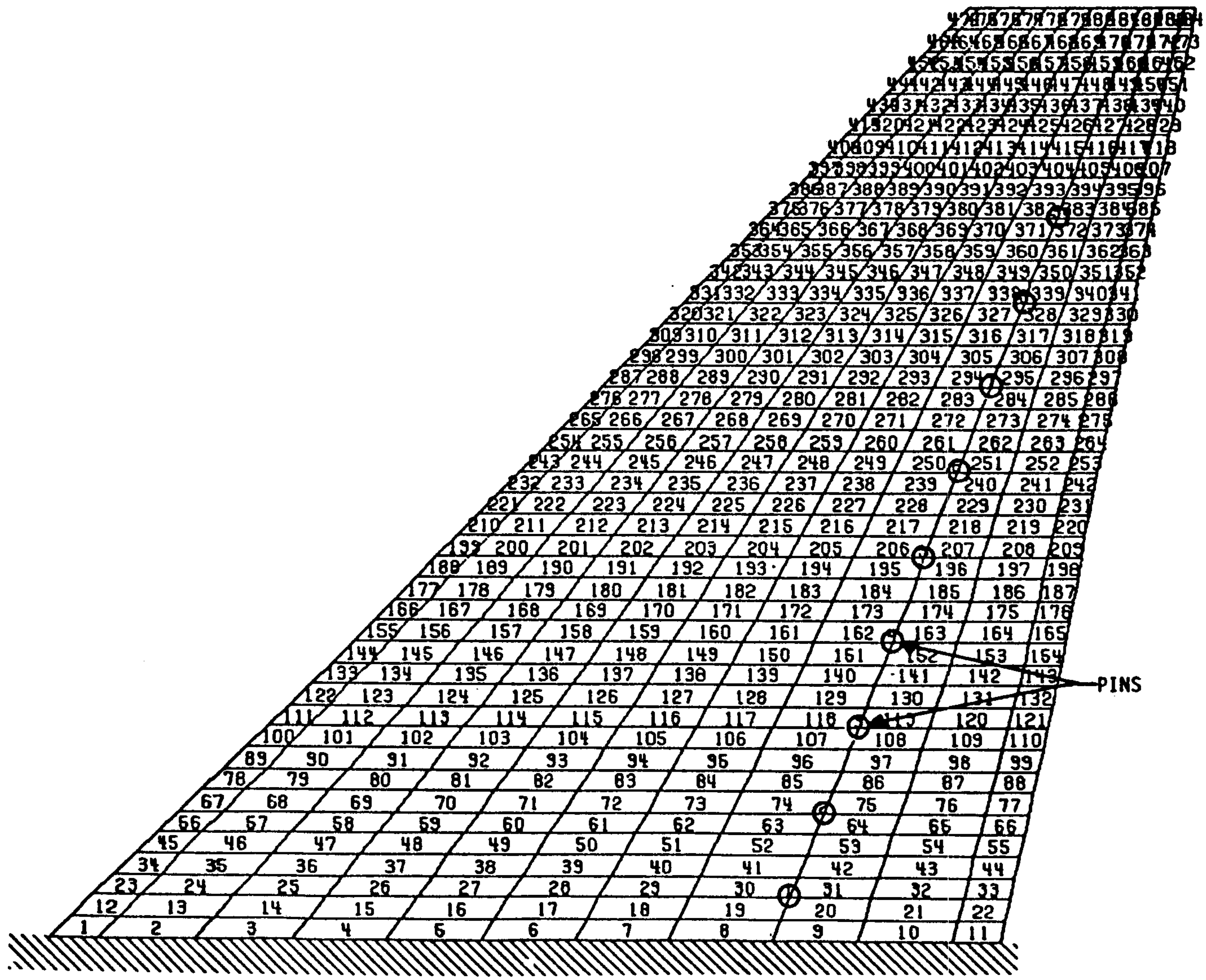

Figure 10. Plate Element Boundaries and Element Numbers for Trailing-Edge Flap Model

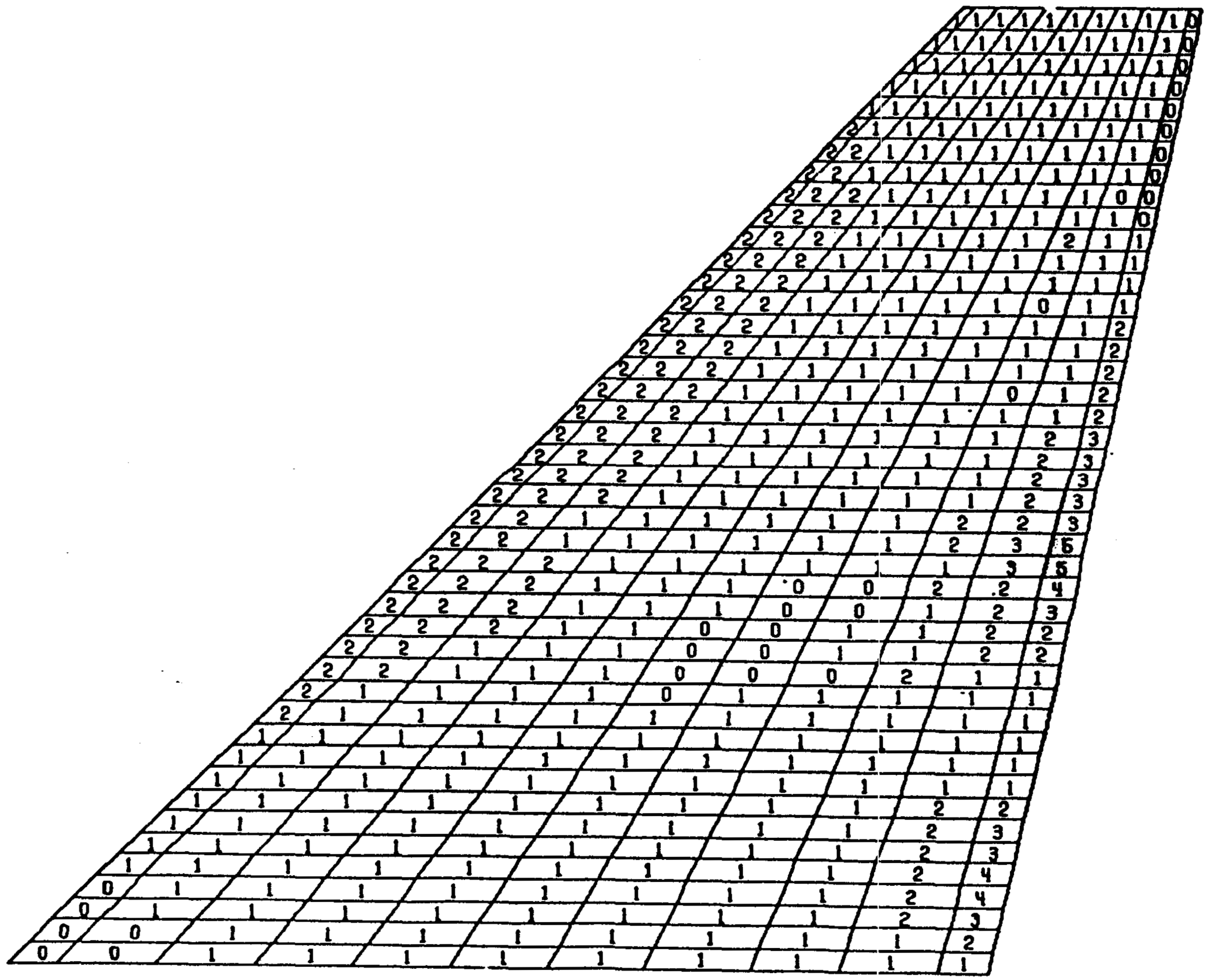

Figure 11. Digitized Principal Stresses at Element Centers for Trailing-Edge Flap Model

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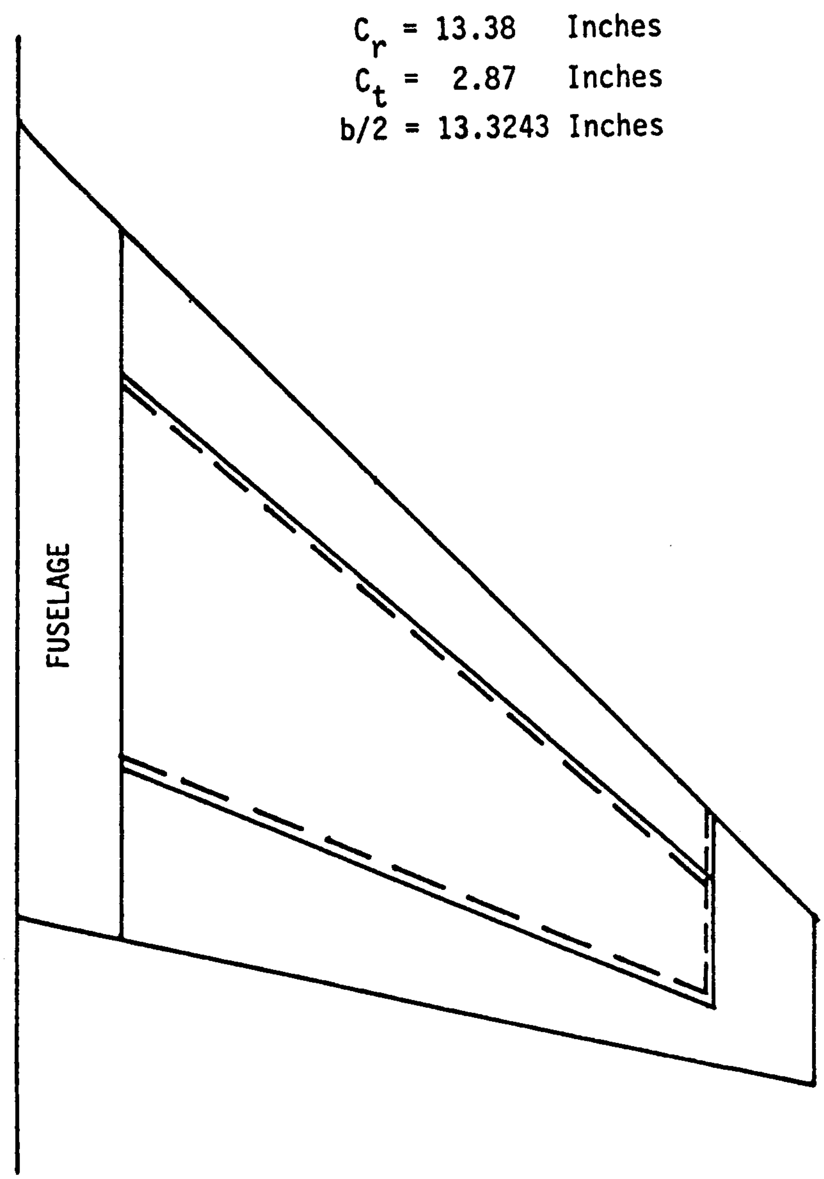

Figure 12. PATHFINDER-II Planview for Trailing- and Leading-Edge Flaps Model

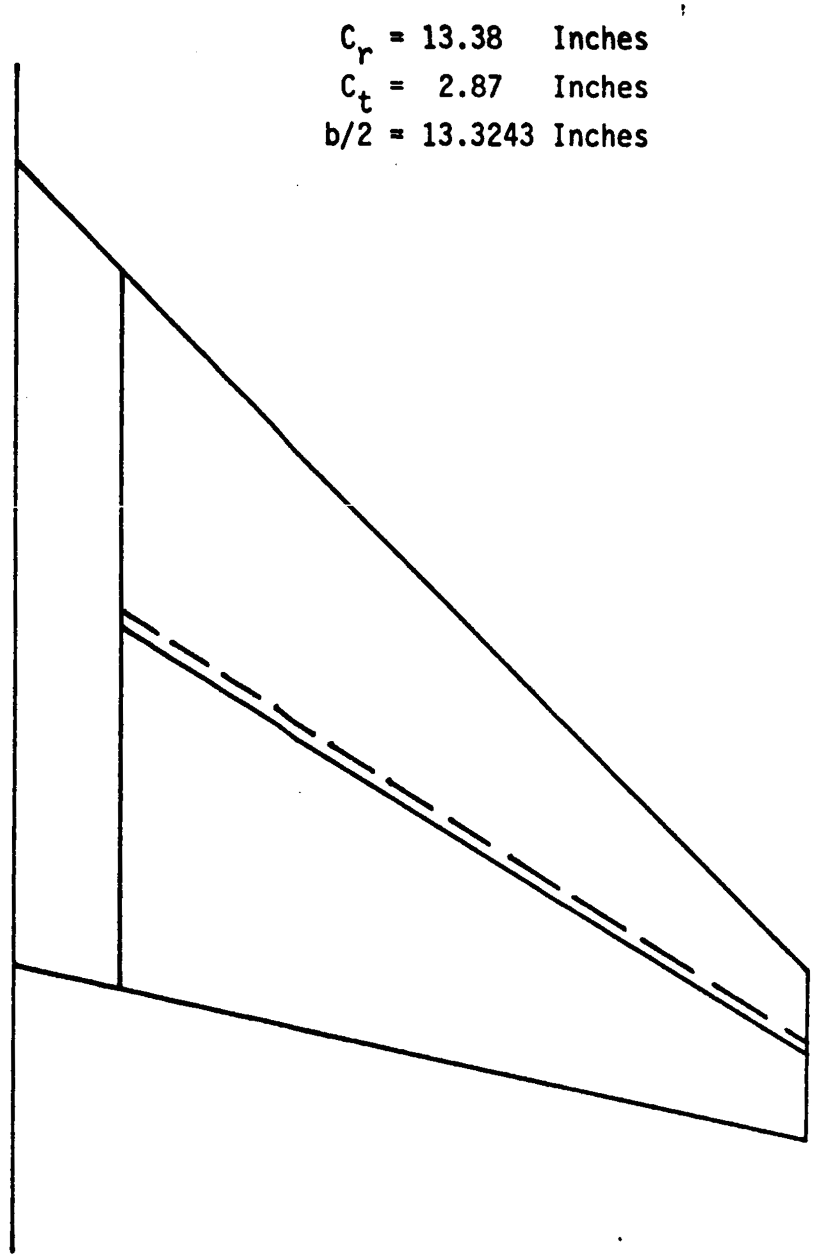

Figure 13. PATHFINDER-II Planview for Flap Model with Hinge Line at 50 percent

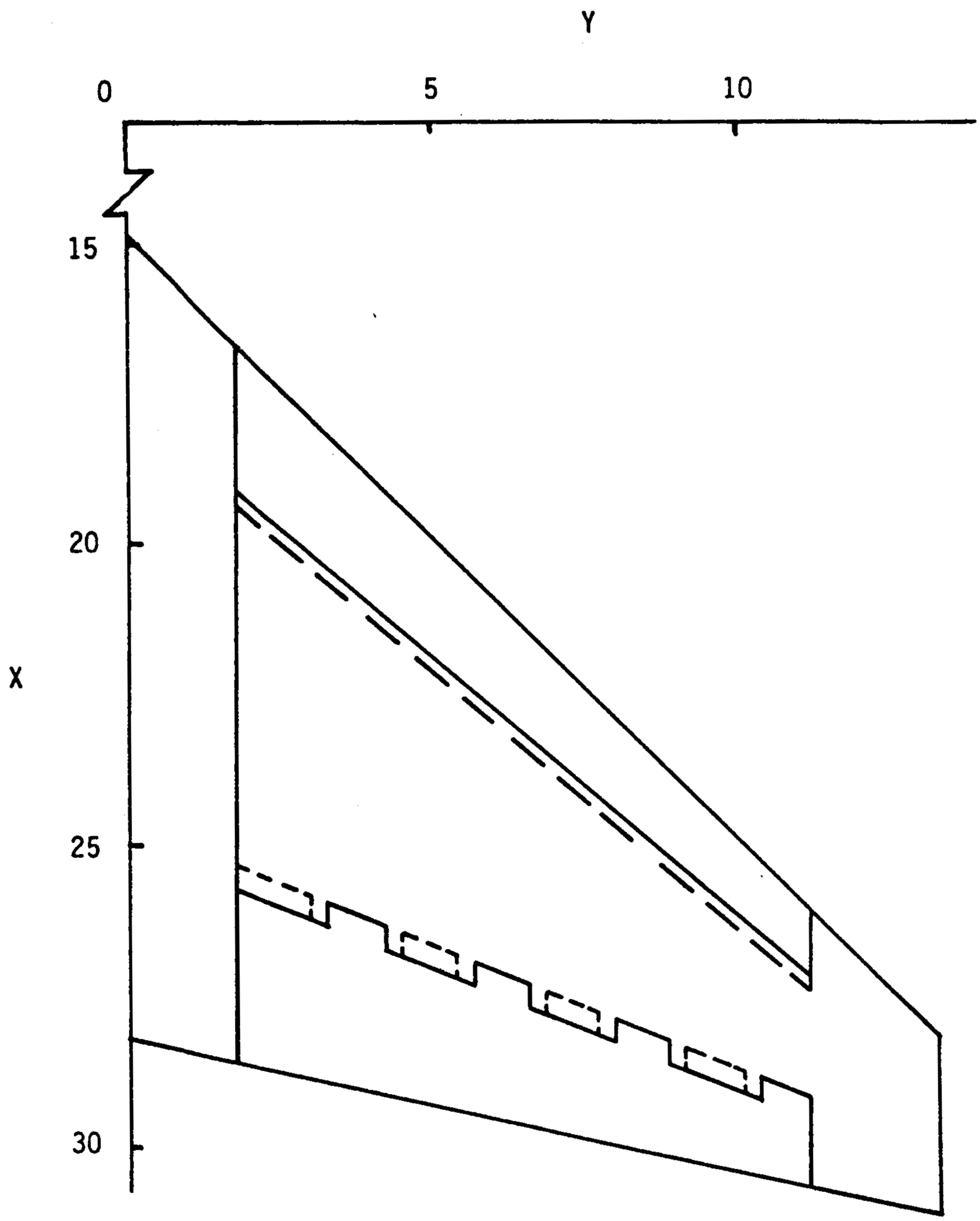

Figure 14. PATHFINDER-II Planview for Alternating Surface Segmented Lap Joint for Trailing Edge-Flap and Single Lap Joint for Leading-Edge Flap (All dimensions are in Inches)

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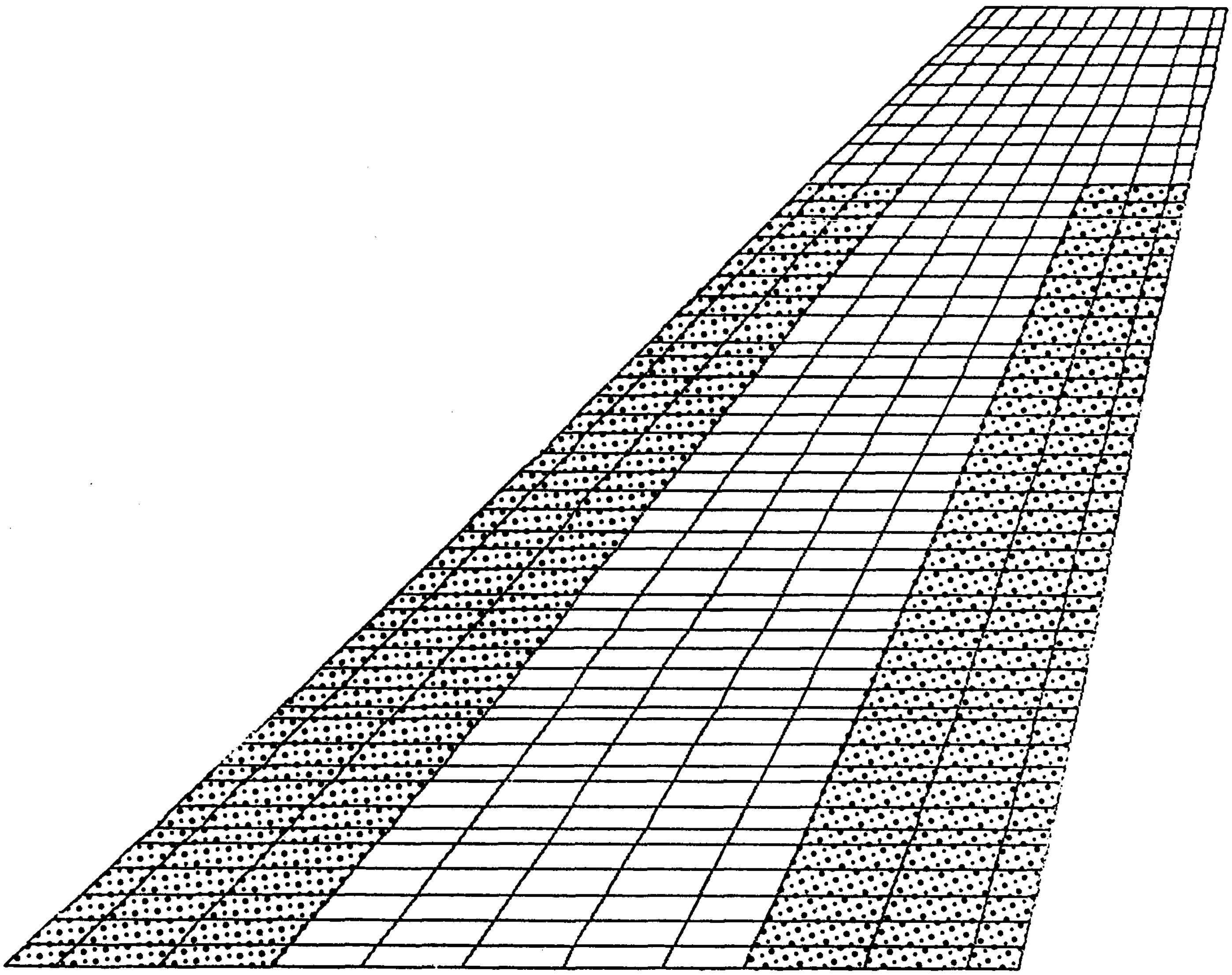

Figure 15. Finite Element Mesh for Alternating Surface Segmented Lap Joint Model.

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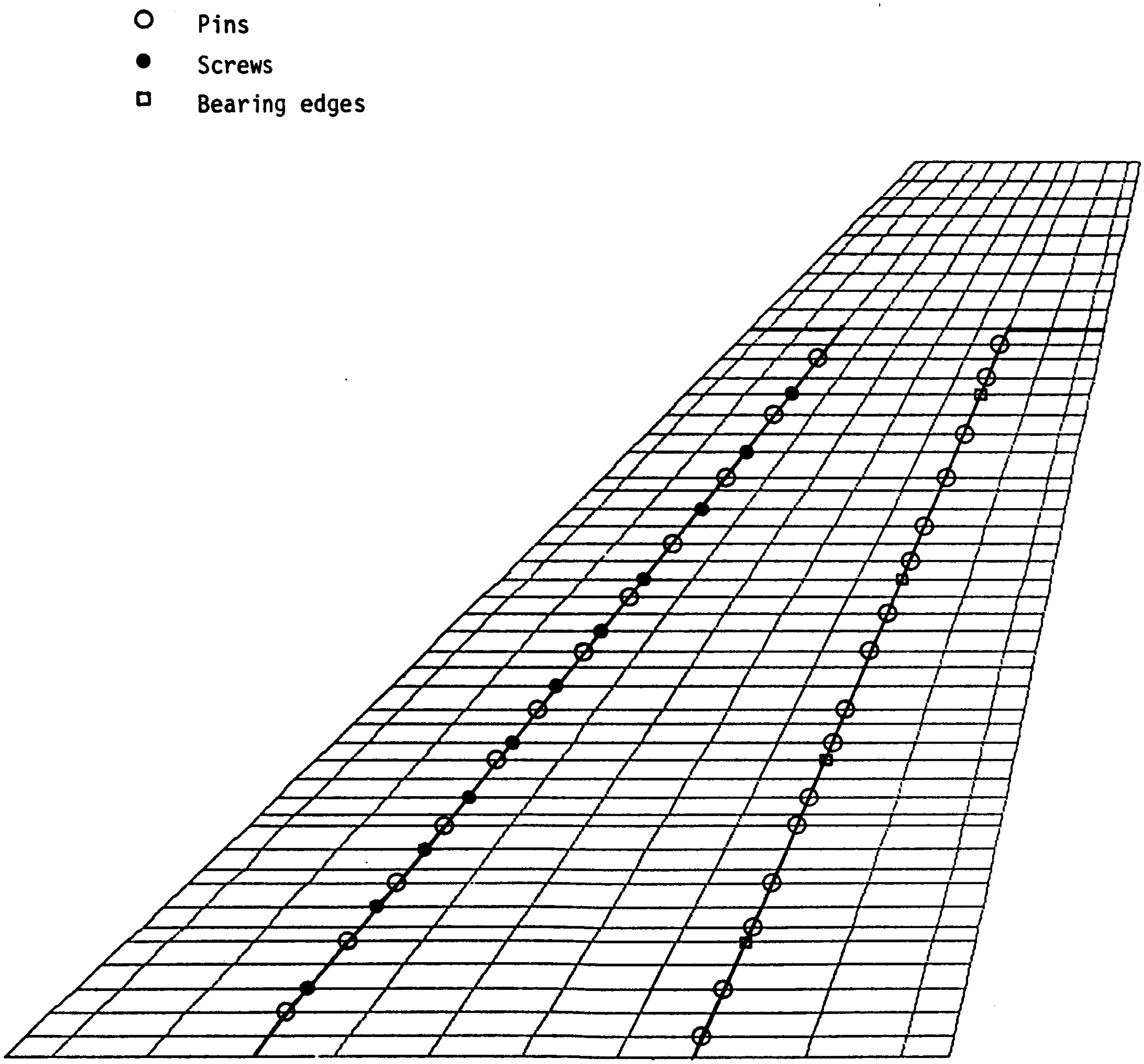

Figure 16. Locations of Pins and Screws for Alternating Surface Segment, Model III.

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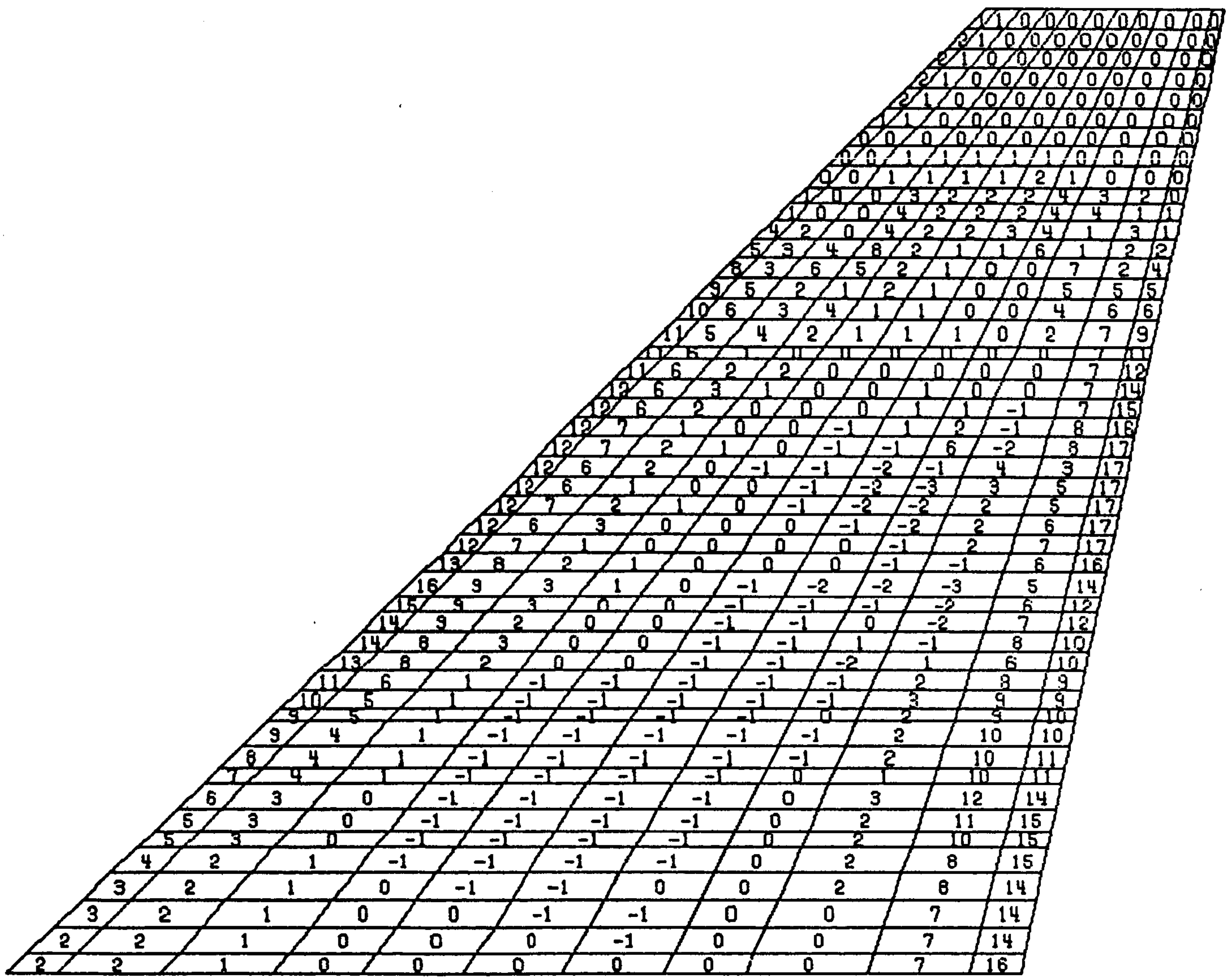

Midsurface Stresses

Figure 17. Digitized Principal Stresses for the Alternating Surface Segmented Lap Joint Model (Model III).

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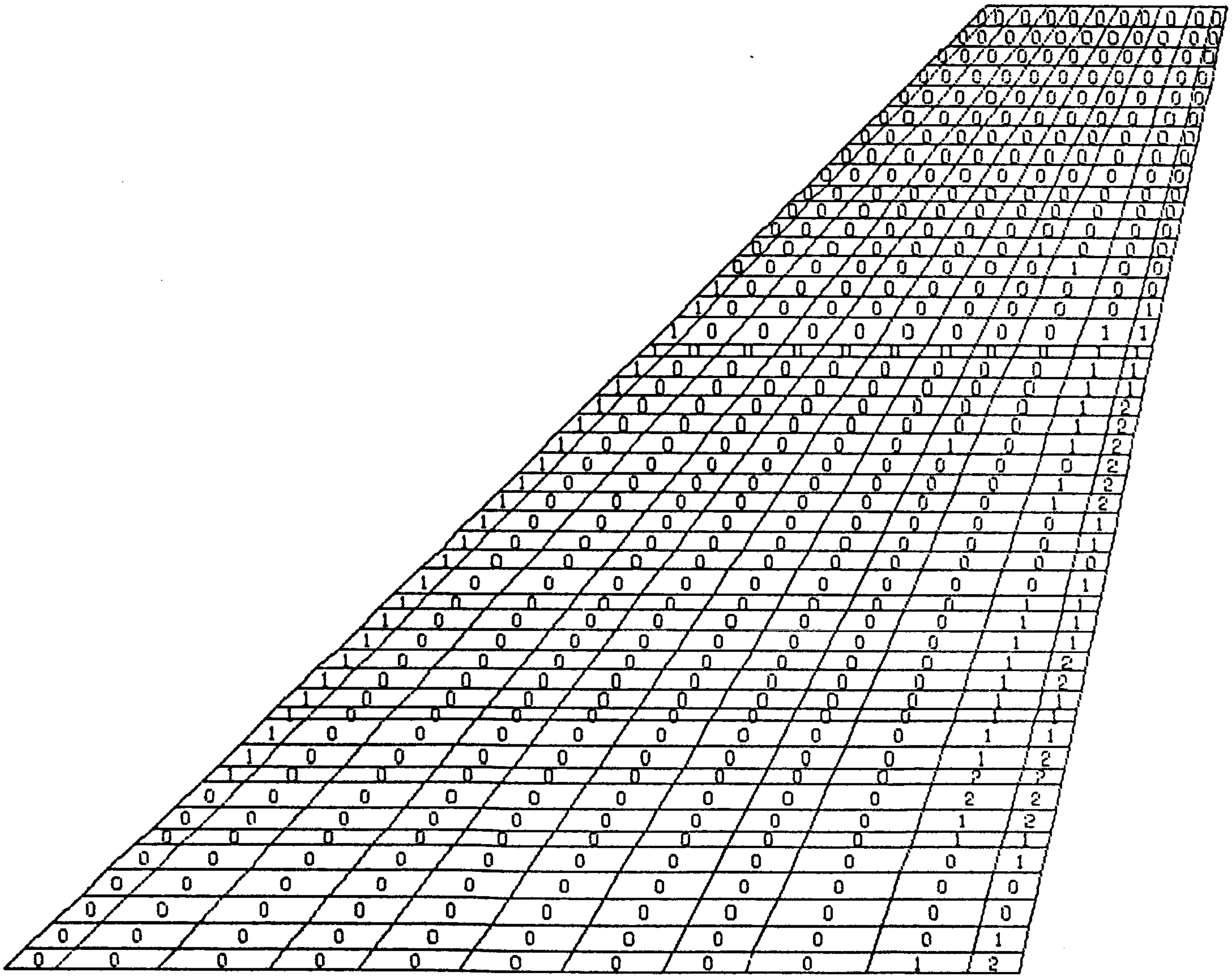

Upper-Surface Stresses

Figure 17. Continued.

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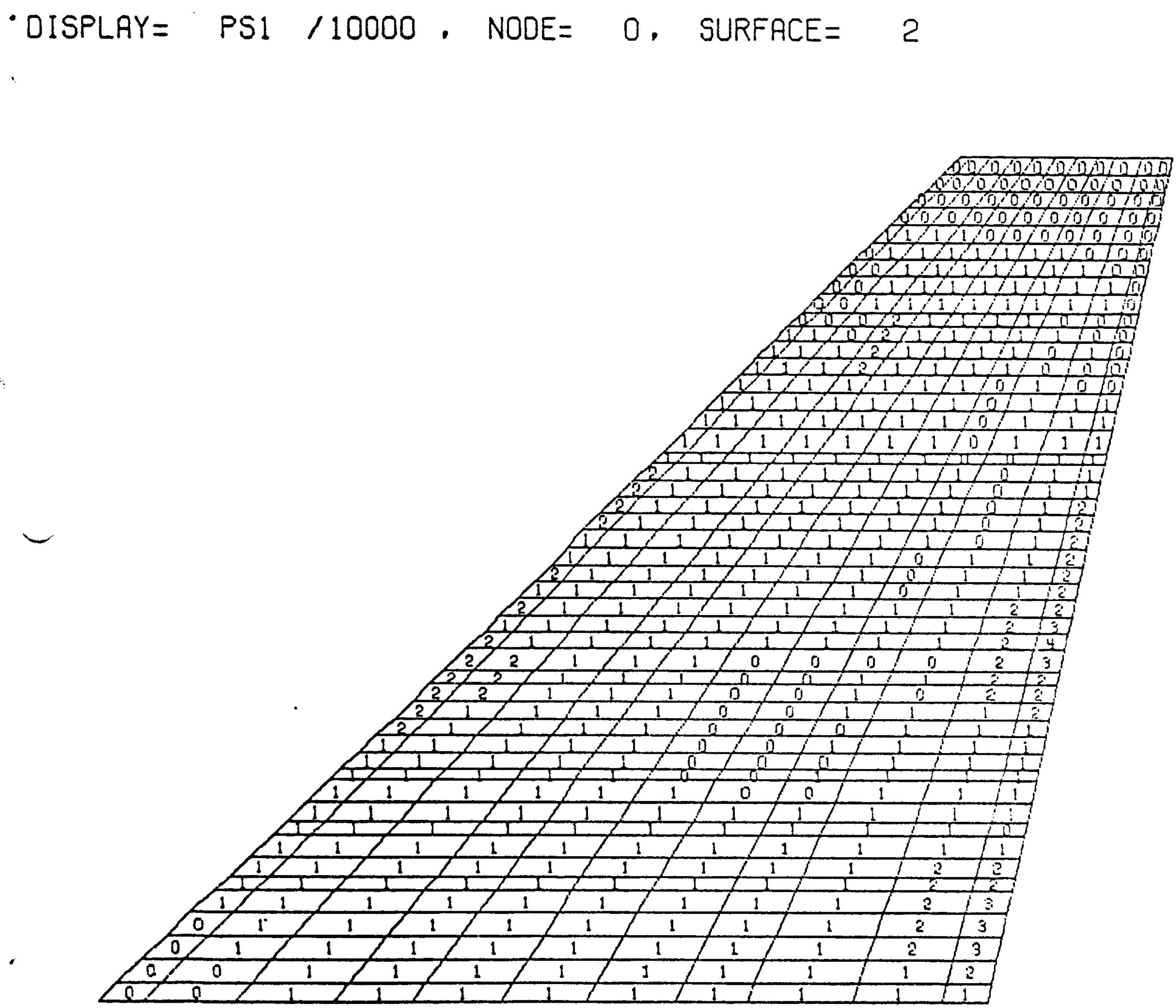

Lower-Surface Stresses

Figure 17. Concluded.

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16. Abstract

Stress analysis of the pathfinder II fighter model was performed to determine a method for leading- and trailing-edge attachment that gives acceptable stress levels. Structural modeling of the wing was done using the finite element code "SPAR". For the models studied, on ordinary lap joint was found to be satisfactory for the leading-edge flap, however, the alternating surface segmented lap joint method of attachment was necessary for the trailing-edge flap to obtain acceptable stress levels.

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